(2)

January 1994

AFRRI

94-1 TECHNICAL REPORT

The TRIGA Reactor Facility at the Armed Forces Radiobiology Research Institute: A Simplified Technical Description

Mark L. Moore

AFRRI TR94-1

Armed Forces Radiobiology Research Institute
8901 Wisconsin Avenue
Bethesda, Maryland 20889-5603

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1994	Technical Report

4. TITLE AND SUBTITLE
The TRIGA Reactor Facility at the Armed Forces Radiobiology Research Institute: A Simplified Technical Description

5. FUNDING NUMBERS
PE: QAXM

6. AUTHOR(S)
Moore, Mark L.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armed Forces Radiobiology Research Institute
8901 Wisconsin Avenue
Bethesda, Md. 20889-5603

8. PERFORMING ORGANIZATION REPORT NUMBER
TR94-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Uniformed Services University of the Health Sciences
4301 Jones Bridge Road
Bethesda, Md. 20814-4799

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
This publication is a revision of the previously published AFRRI Technical Report 86-1.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This publication provides a simplified technical description of the TRIGA research reactor at AFRRI. Topics covered include general principles of reactor operation and a description of the TRIGA reactor and its unique features.

14. SUBJECT TERMS

15. NUMBER OF PAGES
22

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

SECURITY CLASSIFICATION OF THIS PAGE

CLASSIFIED BY:
DECLASSIFY ON:

SECURITY CLASSIFICATION OF THIS PAGE

AFRRI Technical Report 94-1

THE TRIGA REACTOR FACILITY AT THE ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE

A SIMPLIFIED TECHNICAL DESCRIPTION

Mark L. Moore

Accesion For	
NTIS CRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification:	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

January 1994

Radiation Sources Department

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
8901 Wisconsin Avenue
Bethesda, Maryland 20889-5603

Cleared for Public Release; Distribution Unlimited

Contents

Introduction 1
- Mission 1
- Reactor 1

General Principles of Reactor Operation 3
- Fission Process 3
- Control of the Nuclear Reaction 4

Description of the TRIGA Reactor 6
- Reactor Core 6
- Reactor Fuel Element 8
- Control Rods 9
- Neutron Source 11
- Instrumentation 11
- Cooling Systems 11
- Lead Shield Doors 12

Unique Features of the TRIGA Reactor 12
- Modes of Operation 12
- Visible Cherenkov Radiation 12
- Exposure Facilities 12

Summary 15

Introduction

Mission

The Armed Forces Radiobiology Research Institute (AFRRI) conducts research in the field of radiobiology and related matters that are essential to the operational and medical support of the Department of Defense. AFRRI is staffed by members of the three military services and by civilian personnel. In support of its mission, AFRRI operates a research reactor.

Reactor

The reactor, a medium-sized 1.0-megawatt research reactor that generates neutrons and gamma rays for radiation experiments (see figure 1), is a primary radiation source at AFRRI. The reactor is General Atomic's TRIGA reactor; TRIGA is an acronym for training, research, isotope, General Atomic. The TRIGA reactor is designed to be inherently safe, i.e., the reactor's design is such that there is no possibility of an accident that can produce an unsafe condition for the staff or the general public. Since the late 1950s, more than 70 TRIGA reactors have been used worldwide for a variety of applications with no accidents. The TRIGA reactor at AFRRI has been operating since 1962.

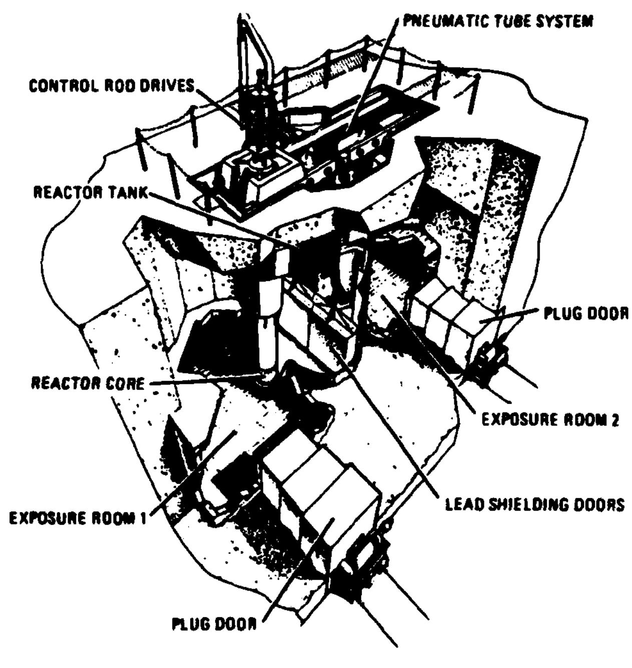

Figure 1. Cutaway view of AFRRI TRIGA reactor.

General Principles of Reactor Operation

Fission Process

At the heart of any reactor is the fission process. Certain elements are likely to undergo fission when they absorb a neutron. One such element is uranium-235. Uranium-235 is our nuclear fuel, and it is packed into fuel elements in the reactor core. When uranium-235 absorbs a neutron, it becomes unstable, breaks up into two or more fragments, and releases a large amount of energy. These fragments are the nuclei of smaller elements and are called fission products. Most of the energy released during fission is manifested in the form of kinetic energy (speed) given to the fission products. When the fission products collide with their surrounding atoms, heat is produced. In addition to the fission products, several extra neutrons and gamma rays are released. Some of the extra neutrons go on to be absorbed by other uranium-235 nuclei, thus producing the nuclear fission chain reaction shown in figure 2.

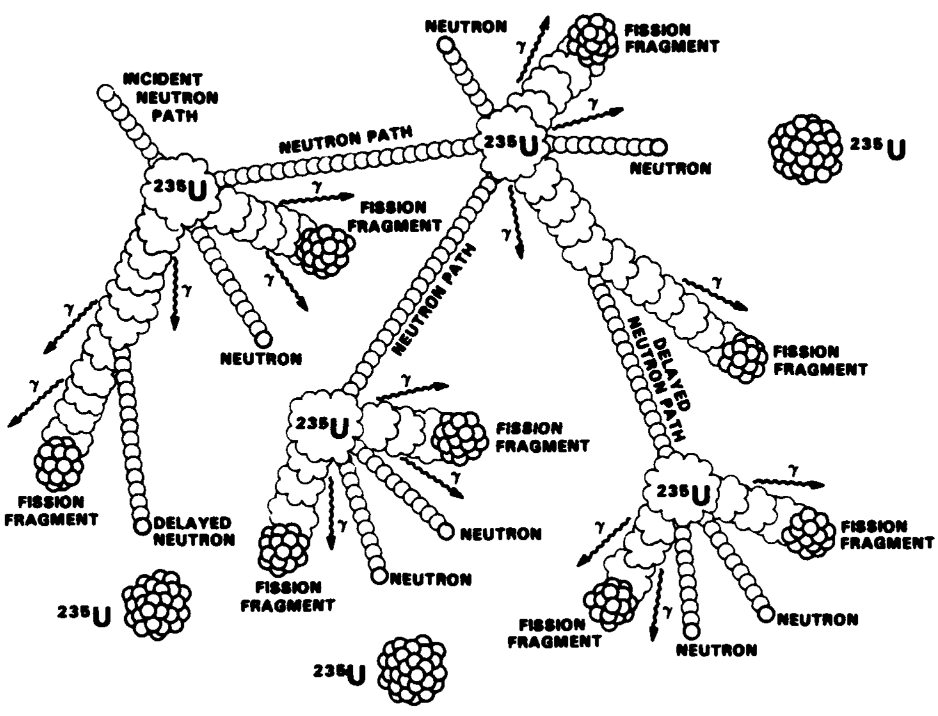

Figure 2. Nuclear fission chain reaction (gamma rays = γ).

The heat produced in the fission chain reaction is allowed to dissipate in a large pool of water. The TRIGA reactor differs from a reactor in a commercial nuclear power plant in that the product of interest is the radiation produced; the heat is considered a waste product. For a reactor in a commercial nuclear power plant, the heat is the product of interest.

An important factor that influences the fission process is the kinetic energy of the neutrons absorbed by uranium-235 nuclei. Uranium-235 nuclei absorb neutrons when the neutrons are travelling relatively slowly (0.025 electron volts or 2,200 meters per second). These slow neutrons are called thermal neutrons. Because neutrons born from fission are usually travelling fast, they must be slowed down to the appropriate speed. This slowing process is called neutron moderation. Neutron moderation occurs when neutrons collide with light atoms such as hydrogen and lose energy by elastic scatter, similar to how pool balls slow down when they collide.

Most of the fission fragments are radioactive and decay to stable (nonradioactive) nuclei by emitting any combination of alpha particles, beta particles, gamma rays, and neutrons. The neutrons emitted by fission products are called delayed neutrons. Although only about 0.7% of all neutrons are delayed neutrons, they are an important component in controlling the nuclear fission chain reaction.

Control of the Nuclear Reaction

The nuclear fission chain reaction can grow indefinitely. A reactor is limited only by how much heat can be removed from the reactor core. To limit the fission rate and thus the heat production rate, neutron-absorbing materials are inserted into the reactor core. The neutron absorbers, called control rods, absorb neutrons in the reactor core, making the neutrons unavailable for the fission process. If enough neutrons are absorbed, there will not be enough neutrons available to sustain the fission chain reaction, and the reactor will reduce its power level.

The neutron absorber used in the TRIGA reactor core is boron carbide. The isotope boron-10 readily absorbs neutrons. The boron carbide is packed into the control rods as shown in figure 3. The reactor uses four of these control rods to control its power level.

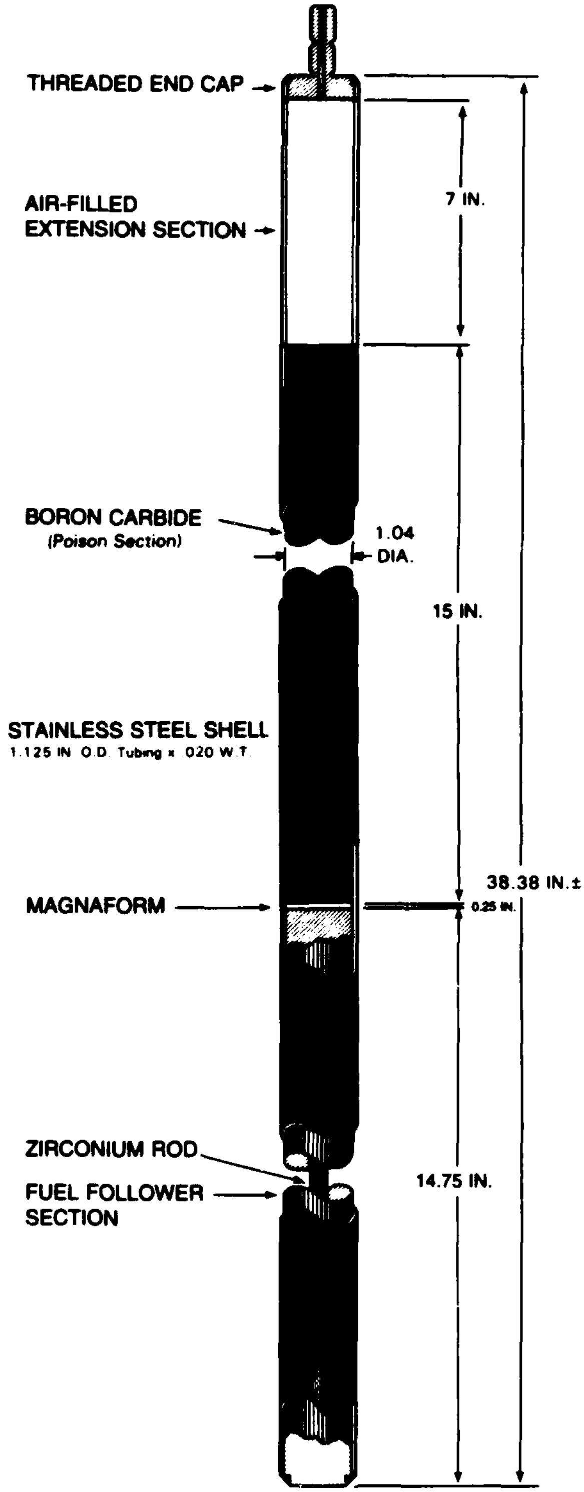

Figure 3. Reactor control rod.

When control rods are pulled out of the reactor, the reactor power increases. The controlled increase in power is due to the effects of the delayed neutrons discussed in the previous section. If all neutrons were born at the instant of fission, reactors would instantaneously increase in power and be difficult, if not impossible, to control. As control rods are inserted into the reactor, the power level decreases.

The generation of heat during the fission chain reaction affects the reactor core's ability to moderate (slow down) neutrons and decreases the density of the uranium-235 fuel atoms and other materials in the core. These effects can be harnessed to help control a reactor. Through judicious selection of materials for fuel elements and fuel element design, these passive factors in reactor control can make the reactor inherently safe.

Description of the TRIGA Reactor

Reactor Core

To produce a controlled, self-sustaining fission chain reaction, the fuel elements containing uranium fuel and the neutron-absorbing control rods must be arranged in a special way; this arrangement of fuel elements and control rods is called the reactor core. In addition to the fuel elements and control rods, the reactor core also contains a neutron source. Figure 4 shows the reactor core.

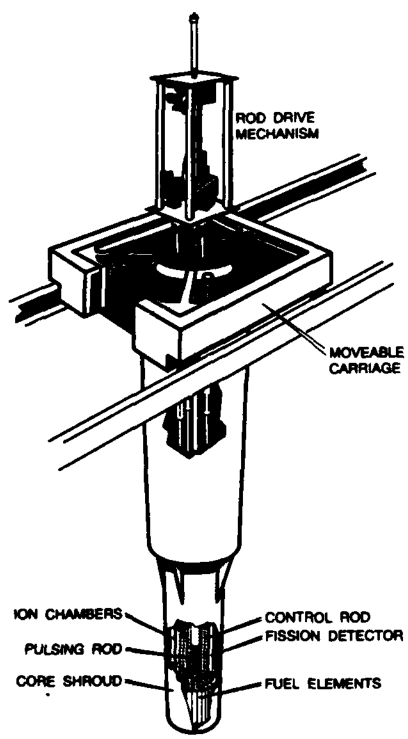

Figure 4. Reactor core.

The reactor core is suspended under 16 feet of water from a carriage just above the reactor pool. The pool is an effective radiation shield, so personnel can safely observe the reactor as it operates. The core support structure shown in figure 4 provides a means to suspend the reactor core. The carriage rides on a track that allows movement of the core from one exposure room to the other exposure room, as shown in figure 5. Movement of the core carriage along the track from one side of the pool to the other is controlled from the reactor console. Approximately 5 minutes are required to move the core from one side of the pool to the other, a distance of 13 feet. The advantages of a movable core are (a) the quantity and character of the radiation reaching the exposure facilities can be controlled, and (b) more than one exposure facility can be used during a day of reactor operations.

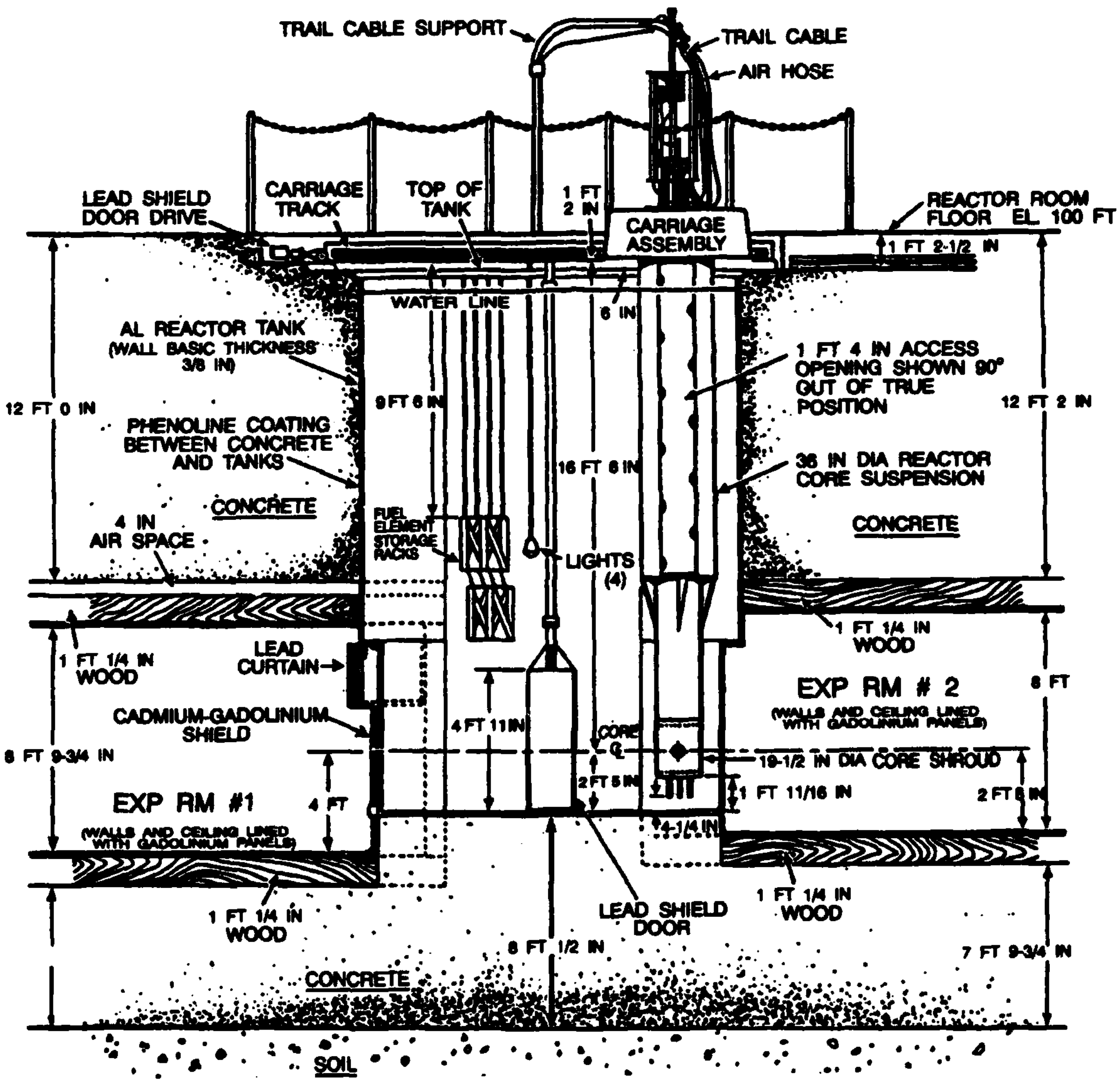

Figure 5. Side view of reactor and exposure facilities.

Reactor Fuel Element

The TRIGA reactor fuel element (figure 6) is designed to capitalize on the inherent characteristics of the fuel to provide safe nuclear reactor control. The fuel element is made of uranium zirconium-hydride (UZrH) metal. The hydrogen in the UZrH metal serves as the primary moderator of neutrons. As the fission chain reaction makes the fuel element hotter, the hydrogen atoms vibrate at increasingly higher frequencies, and thus move rapidly within the metal structure of the UZrH. When a neutron strikes the agitated hydrogen atom, instead of slowing down, it actually speeds up and is unable to

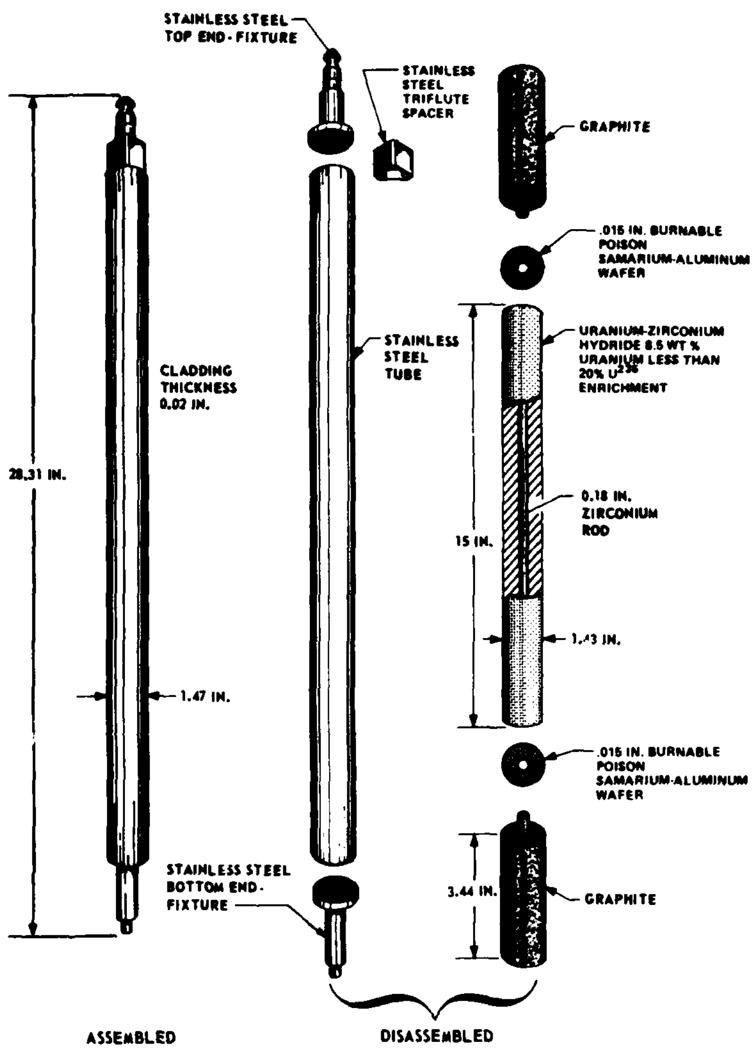

Figure 6. Reactor fuel element.

cause fission. This effect is called the zirconium-hydride disadvantage factor and has an extremely strong influence over controlling the reactor.The zirconium-hydride disadvantage factor makes the TRIGA reactor inherently safe.

Specific design features of the TRIGA reactor fuel element are:

- 0.02-inch-thick stainless steel cladding,
- 0.18-inch-diameter solid zirconium rod in the center of the fuel element to ensure structural integrity,
- 0.015-inch-thick samarium wafer at each end of the fuel element (a samarium wafer is a neutron absorber that helps make the neutron flux uniform in the axial direction and thus extends fuel life), and
- 3.44-inch-long graphite plugs at each end of the fuel element to reflect neutrons back into the fuel element.

The TRIGA reactor can accommodate 4 control rods and up to 87 fuel elements in the reactor core.

Control Rods

Control rods are used to control the rate of the fission chain reaction. Figure 3 shows a standard control rod used in the reactor core. Some of the neutrons in the core that pass into the boron carbide portion of a control rod are absorbed by the boron atoms. This reduces the number of neutrons available for fission in the fuel elements, so the fission rate is reduced. Rod drives that are operated from the control console move the control rods into or out of the core. The amount of a control rod in the core regulates the fission rate. A greater length of a control rod in the core results in a greater number of absorbed neutrons and a lower fission rate. If neutrons are being absorbed at a greater rate than they are being produced, the fission rate decreases, and the production of power and radiation ends. If neutrons are being produced at a faster rate than they are being absorbed, the fission rate, power level, and corresponding radiation increase. Withdrawing just enough of the control rods to match the neutron absorption rate with the neutron production rate achieves a steady-state power level.

There are four control rods in the core of the reactor. One control rod is placed in the center position—the A ring—and is called the transient rod (figure 7). The remaining three control rods are called standard control rods and can be one of the following types: aluminum followed, air followed, or fuel followed. When the neutron absorber section is withdrawn from the core, a section of aluminum, air, or fuel follows in its place. These control rods are placed evenly in the D ring (fourth ring) of the reactor core. The control rods in the fourth ring are called the safe rod, shim rod, and regulating rod. Using the reactor control console, the operator can drive these rods slowly up and down. The operator can also "scram" the rods, allowing them to drop by means of gravity back into the reactor core.

The transient rod can be driven up and down in the same manner as the other control rods. In addition, the transient rod can be rapidly ejected out of the core by means of compressed air. A stopping anvil is positioned above the transient rod to limit the length of the transient rod ejected from the core. Application of compressed air lifts the transient rod from the core until it hits the shock-absorbing anvil. The transient rod can only be rapidly ejected from the core when the reactor is in the pulse or square wave mode. When the reactor is in the pulse mode it is ready for a brief high-power excursion—a sudden dramatic increase in power. In the pulse mode, all control rods scram shortly after the transient rod is ejected from the core. The time to scram is set by

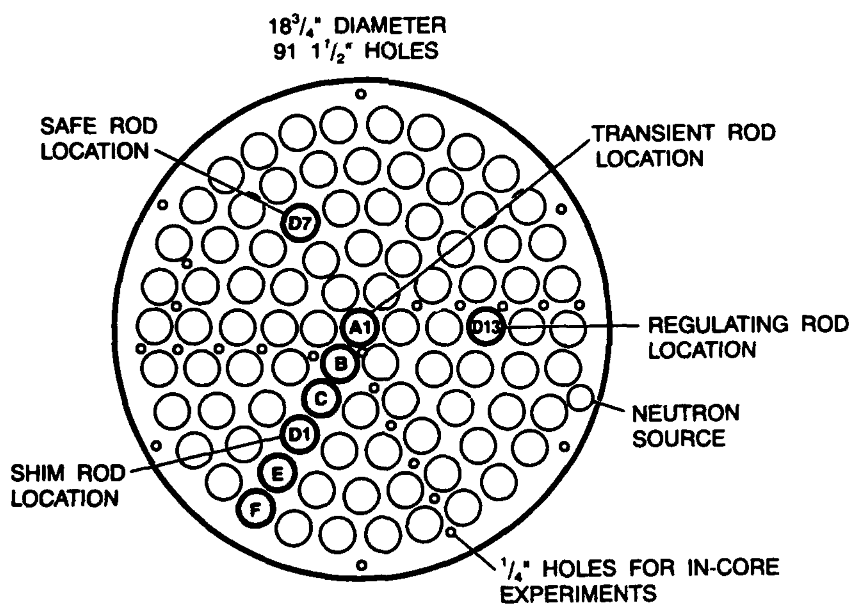

Figure 7. Overhead view of reactor core (upper grid plate).

the operator and is usually 500 milliseconds. When the reactor is in the steady-state mode, the transient rod stays against the anvil and is used like a standard rod.

Neutron Source

A neutron startup source is necessary to ensure constant availability of neutrons in the core when it is in a subcritical configuration: the neutron startup source supplies neutrons to start the self-sustaining fission chain reaction as control rods are withdrawn from the reactor core. The neutron startup source is composed of a mixture of americium, a man-made element, and beryllium, doubly encased in stainless steel. This source produces neutrons when americium spontaneously decays into neptunium and an alpha particle. The alpha particle reacts with the light element beryllium to produce carbon and a high-energy neutron.

Instrumentation

Instruments placed in and around the core monitor important reactor core parameters. These parameters include fuel temperature, neutron population levels, and gamma ray levels. Fuel temperature is measured directly, using thermocouples embedded in at least two fuel elements in the B and C rings of the reactor core. Neutron population is determined by a fission chamber and boron-lined gamma ionization chambers located above the core. These chambers are calibrated to give the steady-state power level. Gamma ray levels are measured by an ionization chamber located above the core. Gamma ray levels are also measured during pulse operation to determine reactor power.

In addition to reactor core instrumentation, pool water temperature, radiation levels in the reactor room and pool, and the status of various safety interlocks are monitored. Pool water temperature is monitored with thermistors located in the pool. Radioactivity of the pool water is monitored by a Geiger-Mueller detector to ensure that fuel elements do not leak fission products and that dust or other particles dropped into the pool does not become activated. The status of various safety interlocks throughout the reactor facility are determined by the positions of microswitches that indicate core position, status of lead shield doors (open or shut), and status of exposure facilities. All parameters of reactor operations are displayed on the reactor control console.

Cooling Systems

Heat generated during fission is removed from the reactor core by means of natural convection. The large pool of water acts as a heat sink. The pool water is kept cool by circulation through a heat exchanger rated at 1.5 megawatts. The cooling water in the heat exchanger is circulated through a cooling tower located on the roof of the building.

Lead Shield Doors

Two lead shield doors are located at the bottom of the reactor pool (figure 5). The doors are aluminum shells 19 inches thick, 5 feet high, and 6 feet wide; they are filled with lead shot and transformer oil. The doors must be opened to allow movement of the core from one side of the pool to the other. They can be closed to provide additional shielding for scientific personnel working in the exposure room on the opposite side of the doors from the core. The edges of the doors are stepped (designed to overlap) to prevent streaming of radiation from between the doors.

Unique Features of the TRIGA Reactor

Modes of Operation

The TRIGA reactor is unique because it can operate in a steady-state as well as in a pulse mode. When the reactor is in the steady-state mode, control rods are withdrawn from the reactor core until the desired power level is achieved. The maximum allowed steady-state power level is 1 megawatt. In the pulse mode, one of the control rods is rapidly ejected from the reactor core by using a special compressed-air control rod drive mechanism. With the rapid ejection of a relatively large amount of neutron absorber from the core, the fission chain reaction escalates at a rapid rate, called a prompt critical excursion. As the fuel heats during the pulse, the inherent effects of the reactor fuel rapidly bring the reactor down to a low power level. The maximum allowed peak power for a reactor pulse is 4,000 megawatts.

Visible Cherenkov Radiation

During a reactor operation, gamma rays born during the fission process strike electrons that surround the hydrogen and oxygen atoms of the pool water. The electrons are then stripped away from the hydrogen and oxygen atoms. The gamma ray energy transferred to the electrons is manifested in the form of high kinetic energy of the electrons. The electrons are moving faster than the speed of light in water. As these energetic electrons decelerate, they emit blue light. This blue light is called Cherenkov radiation. Cherenkov radiation is most dramatic during a pulse operation.

Exposure Facilities

Neutrons and gamma rays pass from the reactor core to an exposure facility where biological systems are irradiated for studies on the effects of radiation. The exposure facilities include two large exposure rooms and a core experiment tube. Each exposure facility has unique characteristics.

Exposure room 1 is the largest of the exposure facilities. It is located north of the pool and is the most frequently used. The room has a variety of shielding, which makes it especially useful to investigators. The exposure room is 20 feet by 20 feet with an 8-foot high ceiling. A semicylindrical section of the aluminum pool wall projects into the south wall of the room. The reactor core can be moved to a position less than 1 inch from the aluminum tank wall and is separated from the tank wall by a small amount of water. A cadmium-gadolinium shield is positioned on the tank projection to absorb the leakage of thermal neutrons from the core into the exposure room. The walls and ceiling of exposure room 1 are made of concrete covered with wood and painted with gadolinium. The concrete is covered by wood because fast neutrons can activate concrete and thus present a hazard to personnel. The wood slows down the fast neutrons emitted from the core, drastically reducing the chances of activating the concrete. After being slowed down by the wood, the neutrons can bounce back toward the interior of the room, but are absorbed by the gadolinium paint before escaping back into the room.

Exposure room 1 is equipped with a pneumatic extractor tube system, which permits quick insertion and withdrawal of samples (figure 8). When in position, the extractor tube

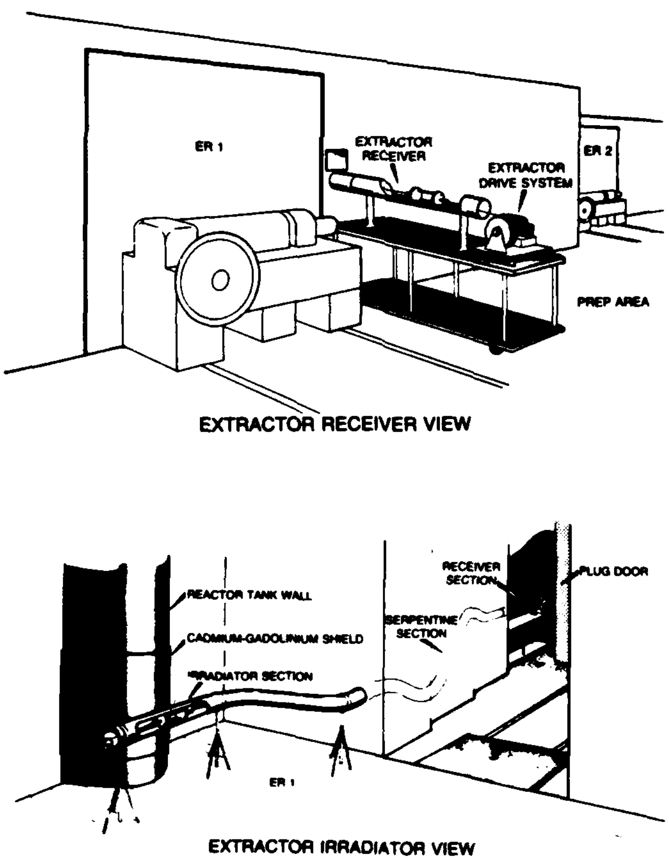

Figure 8. Pneumatic extractor tube system.

extends from directly in front of the core, through the west wall, and into the prep area outside the exposure room. The section of the tube in the wall follows an "S" curve, which prevents the radiation from streaming from the exposure room into the prep area. Samples are placed inside a plastic carrier and positioned in the tube by means of a motorized pulley system controlled from the prep area. The quick retrieval of samples from the exposure room results in greater precision in evaluating the amount of radiation received by the samples, particularly for low-level exposures. This eliminates the delays in moving the reactor core, closing the lead shield doors, and opening the exposure room doors. Retrieval takes place in seconds rather than in the tens of minutes required by procedures for physical entry into the exposure room. The rapid extractor system also reduces radiation exposures to personnel because there is no need to enter the exposure room.

Exposure room 2 is similar to exposure room 1 in construction. The room is slightly smaller, but the ceiling and walls follow the same design as those of exposure room 1—concrete walls are covered with wood painted with gadolinium. The pool wall projects through the north wall of exposure room 2, but it is not shielded with cadmium-gadolinium. As a result, a greater proportion of the neutrons that enter exposure room 2 is thermal. Experiments that need a high thermal neutron component are conducted in exposure room 2.

Samples may also be irradiated in the core itself by using the core experiment tube. The core experiment tube is a hollow aluminum tube with an "S" bend to prevent streaming of radiation. The samples to be irradiated are placed in small polyethylene containers, called "rabbits," which are then loaded into the tube and placed directly into the core. The rabbits may be withdrawn with a modified fishing pole. The core experiment tube is used primarily to produce isotopes, which are used by researchers as biological tags or tracers. The core experiment tube is also used for neutron activation analysis that allows for precise identification of materials within an irradiated sample and has applications ranging from dating precious works of art to forensic analysis of criminal evidence.

Special setups and custom radiation beams are also available. Setups include in-pool portable beam tubes, a pneumatic transfer system, and in-core grid-location tubes. These facilities combined with other materials used in the exposure rooms allow the generation of custom radiation beams.

Summary

The TRIGA reactor has been used at AFRRI to conduct radiobiology research since 1962. The reactor is unique because it operates in both steady-state and pulse modes, its core is visible through a large pool of water, and it includes various exposure facilities. The most important feature of the TRIGA reactor is that the passive control features of its fuel elements make the reactor inherently safe.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

ARMED FORCES INSTITUTE OF PATHOLOGY
ATTN: RADIOLOGIC PATHOLOGY DEPARTMENT

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
ATTN: PUBLICATIONS DIVISION
ATTN: LIBRARY

ARMY/AIR FORCE JOINT MEDICAL LIBRARY
ATTN: DASG-AAFJML

ASSISTANT TO SECRETARY OF DEFENSE
ATTN: AE
ATTN: HA(IA)

DEFENSE NUCLEAR AGENCY
ATTN: TITL
ATTN: DDIR
ATTN: RARP
ATTN: MID

DEFENSE TECHNICAL INFORMATION CENTER
ATTN: DTIC-DDAC
ATTN: DTIC-FDAC

FIELD COMMAND DEFENSE NUCLEAR AGENCY
ATTN: FCFS

INTERSERVICE NUCLEAR WEAPONS SCHOOL
ATTN: TCHTS/RH

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: LIBRARY

UNDER SECRETARY OF DEFENSE (ACQUISITION)
ATTN: OUSD(A)/R&AT

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
ATTN: LIBRARY

DEPARTMENT OF THE ARMY

HARRY DIAMOND LABORATORIES
ATTN: SLCHD-NW
ATTN: SLCSM-SE

U.S. ARMY NUCLEAR AND CHEMICAL AGENCY
ATTN: MONA-NU

WALTER REED ARMY INSTITUTE OF RESEARCH
ATTN: DIVISION OF EXPERIMENTAL THERAPEUTICS

DEPARTMENT OF THE NAVY

NAVAL MEDICAL RESEARCH INSTITUTE
ATTN: LIBRARY

NAVAL RESEARCH LABORATORY
ATTN: LIBRARY

DEPARTMENT OF THE AIR FORCE

BROOKS AIR FORCE BASE
ATTN: AL/OEBSC
ATTN: USAFSAM/RZ
ATTN: OEHL/RZ

U.S. AIR FORCE ACADEMY
ATTN: HQ USAFA/DFBL

OTHER FEDERAL GOVERNMENT

ARGONNE NATIONAL LABORATORY
ATTN: ACQUISITIONS

BROOKHAVEN NATIONAL LABORATORY
ATTN: RESEARCH LIBRARY, REPORTS SECTION

CENTER FOR DEVICES AND RADIOLOGICAL HEALTH
ATTN: HFZ-110

GOVERNMENT PRINTING OFFICE
ATTN: DEPOSITORY RECEIVING SECTION
ATTN: CONSIGNED BRANCH

LIBRARY OF CONGRESS
ATTN: UNIT X

LOS ALAMOS NATIONAL LABORATORY
ATTN: REPORT LIBRARY/P364

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
ATTN: LIBRARY

NATIONAL DEFENSE UNIVERSITY
ATTN: LIBRARY

U.S. DEPARTMENT OF ENERGY
ATTN: LIBRARY

U.S. NUCLEAR REGULATORY COMMISSION
ATTN: LIBRARY

RESEARCH AND OTHER ORGANIZATIONS

AUSTRALIAN DEFENCE FORCE
ATTN: SURGEON GENERAL AUSTRALIAN DEFENCE FORCE

BRITISH LIBRARY (SERIAL ACQUISITIONS)
ATTN: DOCUMENT SUPPLY CENTRE

CENTRE DE RECHERCHES DU SERVICE DE SANTE DES ARMEES
ATTN: DIRECTOR

INSTITUTE OF RADIOBIOLOGY
ARMED FORCES MEDICAL ACADEMY
ATTN: DIRECTOR

NBC DEFENSE RESEARCH AND DEVELOPMENT CENTER OF THE FEDERAL ARMED FORCES
ATTN: WWDBW ABC-SCHUTZ

RUTGERS UNIVERSITY
ATTN: LIBRARY OF SCIENCE AND MEDICINE

UNIVERSITY OF CALIFORNIA
ATTN: LABORATORY FOR ENERGY-RELATED HEALTH RESEARCH
ATTN: LAWRENCE BERKELEY LABORATORY

UNIVERSITY OF CINCINNATI
ATTN: UNIVERSITY HOSPITAL, RADIOISOTOPE LABORATORY

XAVIER UNIVERSITY OF LOUISIANA
ATTN: COLLEGE OF PHARMACY